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13. ABSTRACT *(Maximum 200 words)*

This project examined the use of atomic vapors in an optical correlator for pattern recognition. The nonlinear optics of very thin atomic vapors was studied. This work allowed the demonstration of an optical correlator in a thin cesium vapor. This correlator was able to compare patterns of letters as well as random patterns. The patterns can contain up to 10^5 pixel/cm^2 and the correlation is obtained in 10 microseconds. In addition, methods to improve the performance of the optical correlator were investigated. Experiments showed that motion of the atoms during the excited state lifetime of 30 nsec limited the smallest pixel size to about 30 microns. Two methods that were investigated to improve this resolution were the use of buffer gasses to confine the atoms and laser cooling the atoms to reduce their speed. One set of experiments showed that buffer gasses can either quench the excited state lifetime or limited diffusion of the excited state atoms. Another set of experiments began investigation of laser cooling techniques to slow the atomic motion.

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Atoms For Logic

Final Progress Report

Randall J. Knize

December 13, 1997

U.S. Army Research Office

Grant Number 30201-PH

University of Southern California

A. Statement of the Problem:

The primary aim of this project is the use of atomic vapors for optical information processing. An optical correlator has many potential optical computing applications including; pattern recognition, military target identification, sorting of pharmaceutical pills or other parts, fingerprint identification, neural networks, matrix multiplication, etc. Atomic vapors have the ability to exhibit a sufficient optical nonlinearity so that a correlation containing 10^5 pixels can be performed at a rate approaching 10^6 per sec.

B Summary of the important results:

There were a number of important results obtained during this grant period. The first result was a demonstration of building and using very thin atomic vapor cells with internal dimensions as small as 10 microns. Thin cells are important for use in an optical correlator since diffraction will limit the smallest pixel size. Most previous work with atomic vapors used cells that were at least 1 mm thick. A 1 mm cell can achieve a pixel density of 10^5 cm^{-2} while a 10 micron cell can achieve a pixel density that is 100 times larger. In addition, wall collisions become important in these thin cells. Wall collisions allow degenerate four wave mixing to be observed on transitions that are normally susceptible to optical pumping. Thin cells also allow the observation of light transmission in very dense atomic vapors for the first time, which will allow further investigations of a variety of predicted phenomena.

A theory of degenerate four wave mixing in a saturable absorber was developed for arbitrary input intensities. This theory can be used to examine the efficiency of using degenerate four wave mixing in a saturable absorber for use in an optical correlator.

An optical correlator was demonstrated using cesium atoms confined in a glass cell. This correlator operated at a power of a few mW/cm^2 and could perform a correlation on 10^5 $pixels/cm^2$ in about 10^{-5} seconds. Correlation of letters and random patterns were demonstrated.

The pixel size in this correlator was limited to about 30 microns due to motion of the excited state atoms during their lifetime. We investigated the use of buffer gasses and laser cooling to reduce the excited state motion and therefore be able to achieve smaller pixel sizes and better efficiencies.

It was demonstrated that buffer gasses could quench and limit the diffusion of excited state atoms. One experiment showed that molecular gasses, such as nitrogen, could quench the excited state atoms. Another experiment demonstrated that it is possible to use degenerate four wave mixing to directly

measure for the first time excited state diffusion coefficients. Either of these buffer gas techniques can be used to increase the number of resolvable pixels in the optical correlator.

We are also looking into the use of cold atoms by laser cooling techniques. Cold atoms will have negligible motion; so that grating washout will not occur. This should allow a greatly improved the efficiency and pixel resolution in an optical correlator. Also, since cold atoms have negligible Doppler broadening, all the atoms will resonantly interact with the laser so that the efficiency may be able to be improved by one or two orders of magnitude. We investigated two techniques using laser-cooled atoms. The first method produces a cold cesium atomic beam using Stark effect compensation. The second technique is a new neutral atom trap that uses a focused CO_2 laser beam. This trap can confine cold atoms for very long periods of time due to low photon scattering rates.

C. LIST OF All PUBPLICATIONS and TALKS:

1. "Efficiency of Degenerate Four Wave Mixing in a Two Level Saturable Absorbing Media", R.J. Knize, Optics Letters **18**, 1606-1608 (1993).

2. "Third Order Optical Nonlinearity of C60, C70 and CS_2 in Benzene at 1.06 μm", N. Tang, J.P. Partanen, R.W. Hellwarth and R. J. Knize, Physical Review **B48**, 8404-8408 (1993).

3. "Thin Atomic Cs Vapor As A Nonlinear Optical Medium", B. Ai, D.S. Glassner, R.J. Knize, J.P. Partanen and R.W. Hellwarth. Oral presentation, Paper MHH6, Optical Society of America Annual Meeting, Toronto, Canada, Oct. 3-8, 1993.

4. "Improved Angular Response of Degenerate Four Wave Mixing in K Vapor", D.S. Glassner, B. Ai, R.J. Knize, J.P. Partanen and R.W. Hellwarth. Oral Presentation. Paper MHH5. Annual Meeting of the Optical Society of America, Toronto, Canada, October 3-6, 1993.

5. "A Thin Atomic Vapor as a Nonlinear Optical Medium", B. Ai, D.S. Glassner, R.J. Knize, J.P. Partanen, Applied Physics Letters **64**, 951-953 (1994).

6. "Polarizability of Free Electron Gas Confined to a Spherical Shell", R.J. Knize, Optics Communications **106**, 95-99 (1994).

7. "Laser Sisyphus Cooling in a Trap", B. Hoeling and R.J. Knize, Optics Communications **106**, 202-206 (1994).

8. "Optical Image Processing by an Atomic Vapor", Ivan Biaggio, Jouni P. Partanen, B. Ai, R.J. Knize, and Robert W. Hellwarth, Nature **371**, 318-320 (1994).

9. "Enhancement of Degenerate Four Wave Mixing by Atom-Wall Collisions in Atomic Vapor", B. Ai,

D.S. Glassner, and R.J. Knize. Physical Review **A50**, 3345-3348 (1994).

10. "Optical Correlator That Uses Cesium Vapor", Ivan Biaggio, B. Ai, R.J. Knize, Jouni P. Partanen and Robert W. Hellwarth, Optics Letters **19**, 1765-1767, (1994).

11. "Low-intensity degenerate four-wave mixing at the cesium D1 resonance in thin cells", D.S. Glassner, B. Ai, and R.J. Knize, Optics Letters **19**, 2071-2073 (1994).

12. "Image Processing with Cs Vapor", R.J. Knize, I. Biaggio, B. Ai, D.S. Glassner, J.P. Partanen and R.W. Hellwarth. Oral Presentation. Paper I7 1, Joint April Meeting of the American Physical Society and the American Association of Physics Teachers, Crystal City, VA, April 20, 1994, Abstract in Bulletin of the American Physical Society, **39**, 1133 (1994).

13. "Laser Cooling of a Cesium Beam Utilizing Stark Effect Frequency Compensation", J.R. Yeh, B. Hoeling and R.J. Knize. Oral Presentation. Paper M9 11, Joint April Meeting of the American Physical Society and the American Association of Physics Teachers, Crystal City, VA, April 21, 1994, Abstract in Bulletin of the American Physical Society, **39**, 1168 (1994).

15. "Improving the Angular Response of DFWM in Atomic Vapors", D.S. Glassner, B. Ai, R.J. Knize, J.P. Partanen and R.W. Hellwarth. Poster presentation. Paper QThJ4. International Quantum Electronics Conference, May 12, 1994, Anaheim, CA. Abstract in Technical digest of IQEC'94 conference, Optical Society of America, Washington, D.C., Technical digest series, **9**, 208 (1994).

16. "Laser Cooling of a Cesium Beam Utilizing Stark Effect Frequency Compensation", J.R. Yeh, B. Hoeling and R.J. Knize. Poster presentation. Paper QFD5. International Quantum Electronics Conference, May 13, 1994, Anaheim, CA. Abstract in Technical digest of IQEC'94 conference, Optical Society of America, Washington, D.C., Technical digest series, **9**, 237 (1994).

17. "Fast Response Time, Low Power Optical Correlator Using Alkali Vapor", I. Biaggio, B. Ai, R.J. Knize, J.P. Partanen, and R.W. Hellwarth. Poster presentation. Paper CTuT6. Conference on Lasers and Electro-Optics, May 11, 1994, Anaheim, CA, Abstract in Technical digest of CLEO'94 conference, Optical Society of America, Washington, D.C., Technical digest series, **8**, 171-172 (1994).

18. "Quasi-Electrostatic Trap for Neutral Atoms", T. Takekoshi, J.R. Yeh and R.J. Knize. Poster Presentation. Paper 1H-11. International Conference on Atomic Physics XIV, Boulder, CO, August 2, 1994.

18. "Quasi-Electrostatic Trap for Neutral Atoms", T. Takekoshi, J.R. Yeh and R.J. Knize, Optics Communications **114**, 421-424 (1995).

19. "Optical Information Processing Using Alkali-Metal Vapors", B. Ai and R.J. Knize, Advanced Materials **7**, 319-322 (1995).

20. "Reduced Angular Dependence for Degenerate Four Wave Mixing in Potassium Vapor by Including Nitrogen Buffer Gas", D.S. Glassner and R.J. Knize, Applied Physics Letters **66**, 1593-1595 (1995).

21. "Measurement of the Potassium 4P Excited State Diffusion Coefficient in Xenon Gas using

Degenerate Four Wave Mixing", D.S. Glassner and R.J. Knize, Physical Review Letters **74**, 2212-2215 (1995).

22. "Longitudinal and Transverse Cooling of a Cesium Atomic Beam Using Stark Effect Compensation With the $6S_{1/2}$ to $6P_{1/2}$ Transition", J.R. Yeh, B. Hoeling and R. J. Knize, Physical Review **A52**, 1388-1393 (1995).

23. "CO_2 Laser Trap For Neutral Atoms", T. Takekoshi, J.R. Yeh and R.J. Knize. Oral presentation. Paper TJ 3, Joint Meeting of the American Physical Society and the Canadian Association of Physicists, Toronto, Canada, May 18, 1995, Abstract in Bulletin of the American Physical Society, **40**, 1307 (1995).

24. "A New Method For Direct Measurement Of Excited-State Diffusion Coefficients", D.S. Glassner, B. Ai and R.J. Knize. Oral presentation. Paper WE 7, Joint Meeting of the American Physical Society and the Canadian Association of Physicists, Toronto, Canada, May 17, 1995, Abstract in Bulletin of the American Physical Society, **40**, 1273 (1995).

25. "CO_2 Laser Trap For Neutral Atoms", T. Takekoshi, J.R. Yeh and R.J. Knize. Poster presentation. Paper QTuG17. Quantum Electronics and Laser Science Conference, May 23, 1995, Baltimore, Maryland, Abstract in Technical digest of QELS'95 conference, Optical Society of America, Washington, D.C., Technical digest series, **16**, 68-69 (1995).

26. "Measurements of Excited State Diffusion Coefficients by Degenerate Four-Wave Mixing", D.S. Glassner, B. Ai and R.J. Knize. Poster presentation. Paper QWD18. Quantum Electronics and Laser Science Conference, May 24, 1995, Baltimore, Maryland, Abstract in Technical digest of QELS'95 conference, Optical Society of America, Washington, D.C., Technical digest series, **16**, 131-132 (1995).

27. "Measurement of the Lifetime of the Atomic Cesium $5^2D_{3/2}$ State Using Direct Diode Excitation", B. Hoeling, J.R. Yeh, T. Takekoshi and R.J. Knize, Optics Letters **21**, 74-76, (1996).

28. "CO_2 Laser Trap For Cesium Atoms", T. Takekoshi and R.J. Knize, Optics Letters **21**, 77-79, (1996).

29. "Degenerate Four-wave Mixing in a Two-level Saturable Absorbers", B. Ai and R.J. Knize, Journal of Optical Society of America B **13**, p2408-2413, November 1996.

30. "Direct Measurement of the Cesium 6P Excited State Diffusion Coefficients in Neon Gas using Degenerate Four Wave Mixing", D.S. Glassner, B. Ai, and R.J. Knize, Physical Review A **54**, 3335-3337, October 1996.

31. "Optical Information Processing Utilizing Alkali-Metal Vapors", R.J. Knize, B. Ai, D.S. Glassner, T. Takekoshi, and I. Biaggio. Poster presentation. Twelfth International Conference on Laser Spectroscopy, Capri, Italy June 11-16, 1995. p168-172. Eds. M. Inguscio, M. Allegrini and A. Sasso, World Scientific, Singapore, 1996.

D. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

(1) Randall. J. Knize, Principle Investigator, 1993-1997

Dave Glassner, 1993-1995

Bing Ai, 1993-1996

Jeng-Rong Yeh, 1993- 1996

Tetsu Takekoshi 1993-1997

(2) Ph.D.'s Awarded,

Dave Glassner 1995

Bing Ai, 1996

Jeng-Rong Yeh 1996

Tetsu Takekoshi 1997

E. REPORT OF INVENTIONS (BY TITLE ONLY): None